Failure Analysis of Crankshaft using Finite Element approach

Chetan Kahate, Ashok Keche

Abstract— **The fatigue phenomenon occurs due to repetitive loading on components like crankshaft of IC engine. Fatigue due to combined bending and torsion is most common reason of failure of crankshaft. The objective of this work is to evaluate fatigue life of alloy steel made crankshaft. The crankshaft under study was investigated for failure zone in pin web fillet region. The process wise investigation was made to find out the root cause of fracture occurred in failure zone. The root cause was found to be low surface finish in the pin web fillet region. It caused the undesired stresses in the failure zone. It is observed that due to bad surface finish the fatigue life of existing crankshaft was drastically reduced. The crankshaft is modeled and stresses are analyzed using finite element software. The fatigue life of crankshaft subjected to pure bending and pure torsion loading is obtained during actual testing. The possibility of using fatigue test data from pure bending and pure torsion loading is explored in present work to estimate the fatigue life due to combined loading. In the present study the attempt has been made to improve the surface finish of crank shaft. It is observed that the surface finish is improved 35/% by changing the guide shoe material of crank shaft assembly. The results obtained from simulations are then correlated with experimental results of loading.**

Index Terms— **Fatigue life, bending, torsion, finite element analysis, crankshaft failure.**

I. Introduction

Fatigue is the most commonly encountered type of failure for metallic structures operating under cyclic loading. Fatigue failure often comes without warning and may cause significant damage as well as loss of life. Fatigue failure cannot be stopped from occurring but it is possible to avoid it by proper studies. Hence, Fatigue is the most important failure mode to be considered in a mechanical design. The goal of fatigue analysis in the design process is to perform fatigue and durability calculations much earlier, thereby reducing or removing the need for expensive redesign later on. Physical testing of the component involves considerable cost and time. Carrying out the physical testing always is not a good solution if the cost and time are the constraints. Finite element analysis can be considered as the alternative to the physical testing Crankshaft is an important component of internal combustion engine with complex geometry. Crankshaft experiences a large number of load cycles during its service. Design and Development has always an important issue in crankshaft production industry to manufacture less expensive crankshaft with high fatigue strength. Most of the crankshafts that failed in fatigue were due to combined bending and torsional fatigue. The analysis of fatigue due to combined loading considering combined bending and torsional is done by many researchers.

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Agrawal and Srivastava (2012) presented fatigue behaviour of forged steel crankshaft, subjected to fully reversible cyclic loading, is analyzed using the strain-life theories. And it is found that, that Coffin-Manson strain-life theory is found to be conservative compared to Morrow and Smith-Watson-Topper (SWT) strain-life theories.
Ali & Kadir (2010) Microscopic analysis have been carried out on the surface of journals. Mechanical and metallurgical properties of the crankshaft including chemical composition, micro-hardness, tensile properties and roughness were studied and compared with the specified properties of the crankshaft materials.
Chien and Pan (2003) studied the influence of the residual stresses induced by the fillet rolling process on the fatigue process of a ductile cast iron crankshaft section under bending.
Metkar and et al. (2013) made comparative studies of two methods of fatigue life assessment of a single cylinder diesel engine crankshaft by using fracture mechanics approach viz. linear elastic fracture mechanics (LEFM) and recently developed critical distance approach (CDA).
Osman (2006) analyzed the failure of crank diesel engine crankshaft used in truck, which is made from ductile cast iron. The crank pin was found to break in two pieces before completion of warranty period.

Pandey (2002) investigated the failures of six cylinder engine crankshaft of 0.45% carbon steel. The premature failure was occurred in the web region. The investigation included determination of chemical composition, microstructural examination, evaluation of tensile properties and charpy toughness as well as hardness determination. The fracture toughness was estimated from the charpy energy data. The failure zones in various crankshafts were examined using the scanning electron microscope (SEM) and the micro mechanism of failure in the crankshafts was studied.
Ponson & et al. (2007) investigated the link between failure mechanisms and the geometry of fractures of compacted grains materials, a detailed statistical analysis of the surfaces of fractured Fontainebleau sandstones has been achieved.
Marie Doverbo (2012) established the Correlation between material properties, grinding effects and Barkhausen noise measurements for two crankshaft steels of two different suppliers, using different experimental techniques.
Farrahi & et al.(2010) carried the dynamic analysis and finite element modelling to determine the state of stress in the crankshaft.

Raghunathan and et al. (2014): A detailed study was carried out on crankshafts used in two wheeler made from C45 (EN 8/AISI 1042) steel. Undesirable noise was heard in crankshaft when the engine is in running. This was stated as failure of crankshaft. Material has been peeled off and seemed to be scraped at the central portion of the crankpin. It was the bearing seating place where oil hole also provided. Under analysis the crankpin was identified as tempered. Chemical composition, micro-hardness and microstructure were studied and compared with the specified properties of the crankpin material. Reason for failure is identified as wear due to lower hardness, improper lubrication and high operating oil temperature.

It is observed that Surface finish is one of the important parameters affecting fatigue life of crank shaft. Very few researchers have studied the Effect of fillet radius on surface finish while calculating the Fatigue strength of the crankshaft. Therefore, In the present study the attempt has been made to improve the surface finish of crank shaft. The results obtained from simulations are then correlated with experimental results of loading.

II. Finite Element Analysis

In static analysis the component is assumed to be in equilibrium condition and the effect of various loadings is calculated. A static analysis is the effect of inertia and damping is ignored and the effects of static loading conditions on a structure are calculated. In static analysis it is assumed that loading and response vary slowly with respect to time. Also it is assumed that displacement is very small. The static analysis results of displacements, stresses, strains and forces in structure for components give a clear idea about whether the structure or component will withstand the applied maximum force or not. The results of static analysis are then used as input for fatigue analysis. The objective of FEA is to investigate stresses, experienced by the crankshaft and find out the critical locations. The stresses obtained can then be used to predict the fatigue life and determine the expected failure regions. A single throw of alloy steel crankshaft is used for the finite element analysis. Linear elastic analysis was used since the crankshaft is designed for long life where stresses are mainly elastic. Bending and Torsional loading conditions were considered for the analysis. 3-D solid model was developed in Pro-E 2.0. The geometry created is then imported in HyperMesh for creating the finite element model. The ABAQUS profile in HyperMesh is selected for pre-processing. The boundary conditions are as per the test set up used for experimental testing. As per the customer requirement the crankshaft was subjected to torsion of 50 KN-m. The resonant bending fatigue test was carried out, so the bending load of 59 KN is applied on one plate to create the required bending moment. At exactly opposite side of bending load an accelerometer is fixed. At that point all degrees of the freedom are locked.

A. Material of crankshaft

The material properties Crankshaft of alloy steel are as listed in Table 1 and Chemical composition crankshaft are mentioned in the table 2.

Table: 1 Crankshaft Material Properties

Modulus of Elasticity/	200 GPa
Poisson's ratio	0.26
Yield Strength	470 MPa
Ultimate Tensile Strength	710 MPa
Density	7850 Kg/m3
Surface roughness	2.5µm

Table 2 : Chemical composition crankshafts

Element	Specified content	A	B, C	D, E
C %	0.35- 0.40	0.38	0.38	0.36
Si %	0.45- 0.65	0.51	0.50	0.55
Mn %	1.30- 1.50	1.37	1.38	1.32
P %	<0.025	0.014	0.010	0.008
S %	0.018- 0.033	0.024	0.024	0.021
Cr %	0.20- 0.30	0.23	0.23	0.22
V %	0.08- 0.12	0.095	0.093	0.10
Al %	0.005- 0.030	0.020	0.021	0.011
Cu %	<0.35	0.24	0.20	0.30
N %	0.0090- 0.0200	0.0115	0.0108	0.0103

B. Static analysis results

The figure 1 and 2 shows the equivalent (von-mises) stresses developed in fillet region under the bending and Torsional loads respectively. Figure 3 shows the view of the fillets showing the areas under compression with blue colour and those under tension with red colour due to applied bending moment. The maximum stress obtained at the fillet is 753 MPa which is well below the yield strength of the material for pure bending. For individual moment loading, areas near the fillets as well as the area near to oil holes are mostly affected. From figure 4, it is seen that maximum stress is 741 Mpa. Combined (Bending + Torsion) loading shows that the stresses developed are the cumulative effect of stresses of individual loadings. From figure 5, it is seen that maximum stress is 639 MPa which is less than that for individual bending or individual moment loading

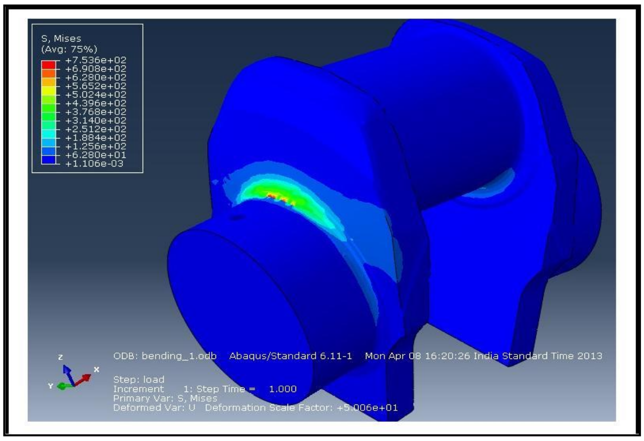


Figure 1: Von-Mises stresses result due to bending.

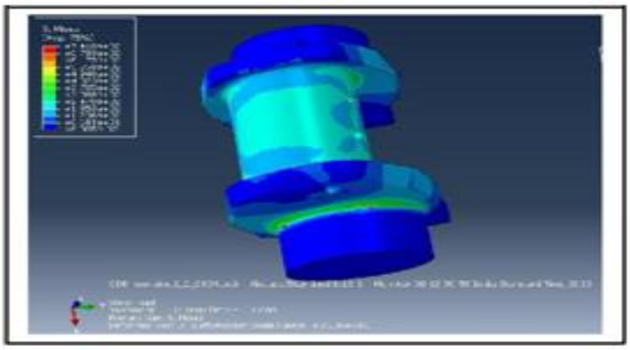


Figure 2: Von-Mises stresses result due to Torsion

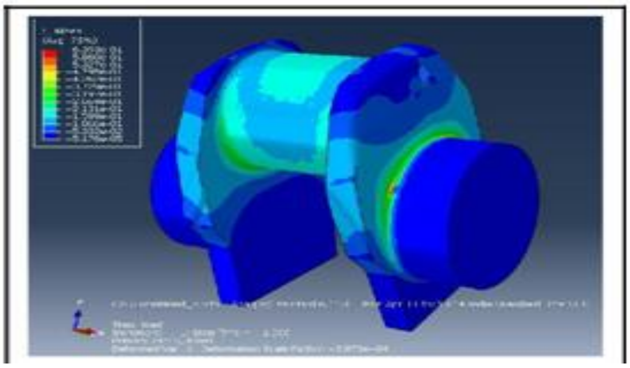


Figure 3: Von-Mises stresses result due to combined bending and torsion.

III. Fatigue Life Assessment by Finite element analysis:

The main objective of estimating the fatigue life of crankshaft is to investigate the behaviour of crankshaft under complex loading conditions. Due to the repeated bending and twisting, crankshaft fails, as cracks form in fillet area. Fatigue analysis of crankshaft is done in MSC Fatigue.The results obtained from the static analysis are used as input to the fatigue analysis. Fatigue results are tabulated as below.

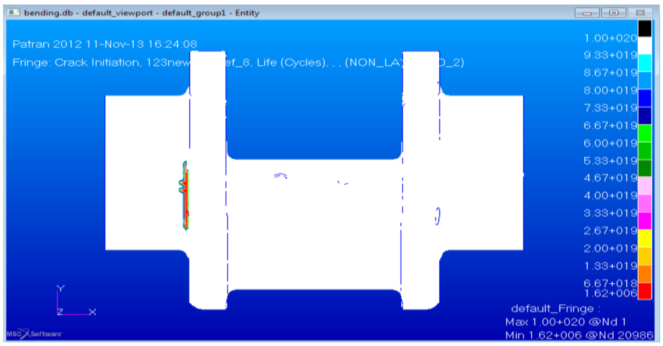
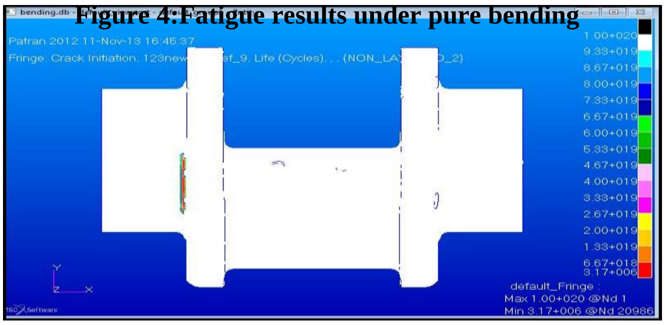


Figure 4:Fatigue results under pure bending



igure 5:Fatigue results under pure Torsion

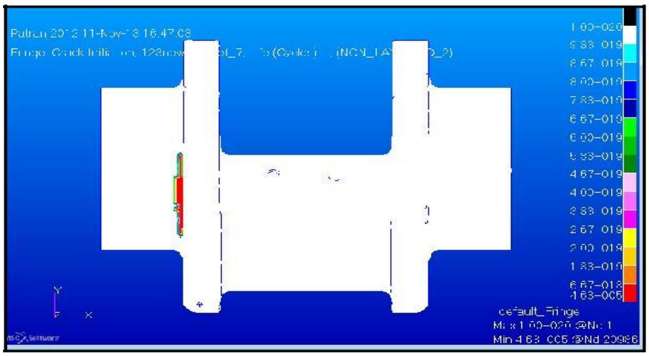


Figure 6: Fatigue results under combined Bending and Torsion

IV. Experimental Analysis of Fatigue Life of Crankshaft

Five crankshafts were sent to fatigue testing lab from a lot of significant production run as per customer specification, out of which one crankshaft sample was found to be fail at the fillet radius of crankshaft. The investigation was initiated to find the failure modes and its analysis. This failure is common in case of components which are subjected to fatigue loading i.e. at highly concentrated stress area. The crankshaft were forged then machined and induction hardened on pin and journals up to depth of 2- 7mm. After induction hardening it is tempered at 230 degrees to relive stresses developed inside the crankshaft due to machining and induction hardening.

The experimental fatigue testing in bending is based on the tuning fork method. The experimental results are compared with FEA results. In the tuning fork method the single throw of crankshaft is assembled with two plates that become tines of the tuning fork, the total assembly of tines, crankshaft, stringing rod and stringing rod holder is hanged by ropes as shown in Figure 8. A crankshaft section is attached to two heavy steel tines and the system acts as a large tuning fork.

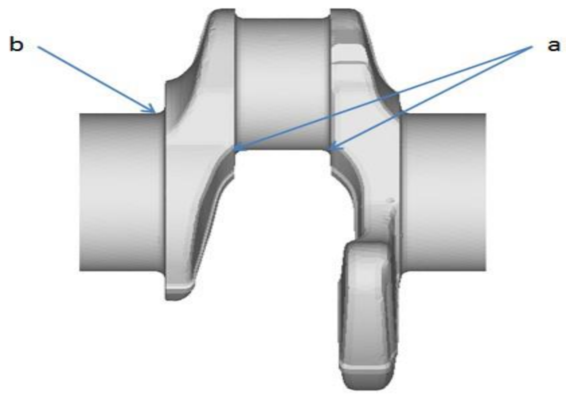


Figure7: Strain gage mounting locations on crankshaft

The critical locations in the crankshaft section are pin fillets, oil holes and journal fillets, where crack initiation is predominantly occurs and develops in to surrounding areas. The strain gauges were therefore mounted at these critical locations. These locations are labelled as ‘a’ and ‘b’ shown in Figure 7.

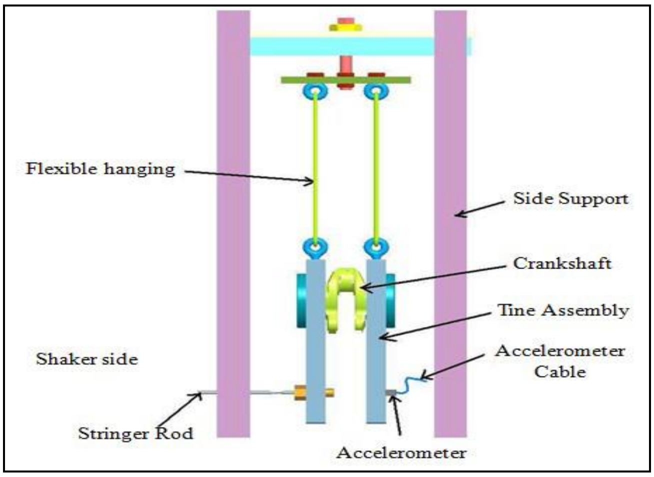


Figure 8: Experimental setup for fatigue life test

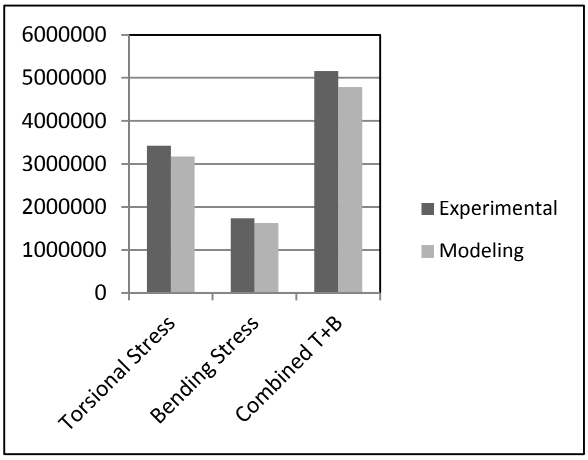


Figure 9: Variation of von mises stress Actual vs modeling

V. Results and Discussion

The results obtained by FEA and experiments are as shown in fig 9. It is observed that the experimental results show good agreement with modelling results.

1) For pure bending test the difference between experimental and modelling results is 8%.

2) For pure torsional test the difference between experimental and modelling results is 7%.

It is observed that experimental results show more fatigue life than the modelling results due to certain assumptions made during calculations.

Table: 2 Fatigue life comparisons Actual V/s Modelling

Test	Modeling Results (Cycles)	Experimental Results (Cycles)	Difference between Exp. and Modeling results (%)
Pure Bending	3170000	3423600	8
Pure Tosional	1620000	1733400	7
Combined Torsional and bending	4790000	5157000	7.5

VI. Conclusions

Fatigue life analysis of forged steel crankshaft was done using finite element methods and experimental methods. FE model of crankshaft is created using Hypermesh, FE analysis is done in ANSYS V14.5 and fatigue life was calculated with the help of MSC Fatigue software. The following conclusions are drawn from the present study:

I. The static stress analysis is required to find out the maximum stresses and critical locations in the crankshaft. Due to complex geometry finite element analysis is necessary to obtain the stresses in the crankshaft.

II. It is observed that the maximum stress is obtained at the pin fillet area which is found to be 753 MPa (Bending), 741 (Moment) and 639 (Bending + Moment).

III. It is observed that the experimental results show good agreement with modelling results.

IV. It is observed that the difference between experimental and modelling results for pure bending test is 8%.

V. It is observed that the difference between experimental and modelling results for pure torsional test is 7%.

VI. It is observed that the difference between experimental and modelling results for combined test is 7.5 %.

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